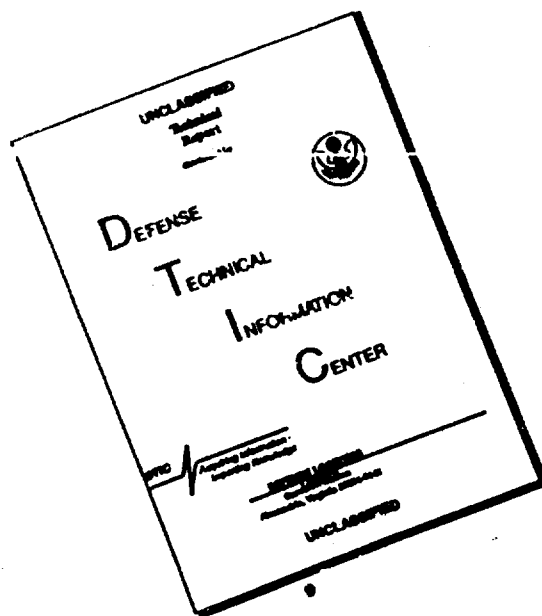


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ACTIVE AND PASSIVE DEFENSE

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This book deals primarily with blast shelters, which are a passive form of defense. However, passive defense cannot be discussed meaningfully without understanding the relationship to active defense, i.e., intercepting and destroying the attacking bombers and ballistic missiles. Both active and passive defense have the same purpose--to save lives and the tools necessary for recovery. This chapter will describe the technical aspects of active defense, particularly ballistic missile defense, then discuss the difficult question: which is more effective, active or passive defense--or some combination of the two?

Bomber Defense and Ballistic Missile Defense

Ten years ago active defense referred to defense against high-altitude bombers. Then the intercontinental ballistic missile (ICBM) was developed and the defense picture changed drastically. Our bomber defense had no capability to intercept ballistic missiles. Moreover ballistic missiles could destroy vital elements of the bomber defense, which meant that the bomber defense became ineffective even against bombers. This situation led to a period of intense effort to develop a defense against ballistic missiles, with relative indifference toward possible improvements in defense against bombers.

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This is a slightly revised version of P-3165 (Active and Passive Defense) dated August 1965. This paper will be a chapter in a soon to be published book on Civil Defense, edited by Professor Eugene Wigner. The modifications, all in the last section of the paper, are not substantive. Some numbers were changed so this chapter would be consistent with the rest of the book and a few editorial changes were made for the sake of clarity.

During the past ten years considerable progress has been made on ballistic missile defense, but just as bomber defense without ballistic missile defense is of little value, so also is the opposite true. Cities need not be attacked in the first minutes of the war; hence bombers can be used for this purpose just as well as missiles. Indeed there is a good reason for an aggressor to concentrate his initial attack on military targets. These targets, particularly aircraft and missiles, must be struck quickly--by missiles--in order to keep retaliation to a minimum.

The remainder of this chapter will be concerned only with the problem of ballistic missile defense. But the reader should keep in mind that effective bomber defense is itself a difficult problem, which would not be solved automatically if the ballistic missile defense problem were solved. The heart of the difficulty is this: within or near enemy territory modern bombers can fly at low altitude--a few hundred feet above the ground--so that detection by ground-based radar is possible only at short range. As a result, a number of bombers can concentrate their attack in a narrow corridor--avoiding most of the defenses and saturating the rest. The problem is further complicated if the bombers are equipped with many small, nuclear-armed missiles which are fired outside the range of the bomber defense radar and fly at such a low altitude that they cannot be intercepted by the ballistic missile defense. With such missiles even a single bomber might saturate the short-range defenses.

Approaches to the bomber-defense problem using air-based missile and radar platforms to achieve area coverage, as well as invulnerability to missile attack, look promising but still have major technical difficulties.

Technical Aspects of Ballistic Missile Defense

To understand the ballistic missile defense problem it is necessary to know some of the characteristics of an ICBM. For this purpose it is convenient to distinguish three fairly distinct parts of the ICBM trajectory.

The first is the launch phase when the rocket motors are firing, and the ICBM rises with increasing speed. Thousands of delicate components must operate in a precise manner during this phase, and the missile is in its most vulnerable state. Small perturbations can grossly affect its overall performance. This part of the trajectory lasts a few minutes and terminates when the final-stage rocket motor is turned off, well outside the atmosphere.

The next phase, beginning when the nose cone--containing the nuclear warhead--is separated from the rocket and lasting until the nose cone again reaches the sensible atmosphere--an altitude of a few hundred thousand feet--is called the mid-course phase. This phase is by far the longest part of the flight; it takes the missile from a point essentially over its home base to a point above its target in enemy territory. The nose cone, with the warhead inside, flies freely during this phase, similar to a cannon ball, except that the trajectory is outside the atmosphere. For the nominal ICBM range--5500 nautical miles--this part of the trajectory lasts approximately twenty minutes and reaches a height above the earth's surface of about 700 miles. The speed of the nose cone during this phase is roughly four miles per second.

The remainder of the trajectory--the terminal phase--is characterized by the interaction of the nose cone with the atmosphere. For the minimum-energy trajectory, the ICBM approaches the target on a line about twenty-three degrees above the horizon. The nose cone does not slow down appreciably until it is quite close to the ground--fifty thousand feet or less depending upon detailed design--so that most of the terminal phase of the trajectory is traversed at the speed of four miles per second. The duration of this phase, considered to begin at an altitude of a few hundred thousand feet, is less than one minute.

Difficulties with Launch Phase and Mid-Course Ballistic Missile Defense

The above description suggests that it would be advantageous to attack the ICBM during the launch phase. The missile is over enemy territory, it is moving relatively slowly, and it is most vulnerable.

Even non-nuclear weapons could be effective in destroying the missile, and nuclear weapons would have large kill radii. Launch-phase defense has the additional advantage of area coverage, i.e., providing protection for the whole country. Systems using this approach have been studied. The most studied system--BAMBI--consists of satellites that detect ICBM launches by infra-red emission from the rocket motor. On detection the satellite releases an infra-red homing missile with an intercept range of a few hundred miles.

The difficulty with this concept is that, to handle a concerted attack of ICBM's, a large number of satellites must be on station. A large number on station implies a much larger number in orbit--perhaps thousands. Studies of the BAMBI system, making reasonable estimates of reliability and kill probability, lead to astronomical costs for such a defense. To make matters worse, it may be feasible for the offense to employ cheap infra-red decoys that could drain the satellite interceptors and allow the real missiles to go unscathed.

Mid-course ballistic missile defense, like launch-phase defense, has the advantage of operating far from friendly territory and providing area coverage, and in addition has the advantage of requiring only a small number of ground-based installations. The latter fact makes this type of defense especially attractive from the point of view of cost. Unfortunately, mid-course ballistic missile defense faces a great difficulty.

There is no atmosphere in the mid-course phase--no drag forces--and therefore any objects, no matter how lightweight, if dispersed with the nose cone, will follow along in essentially the same trajectory. This property of the mid-course phase permits the offense to employ lightweight decoys to fool radar--which is the only practical method of detection during this phase. For example, metallized balloons shaped like the nose cone can provide indistinguishable radar echoes, or light metal wires of appropriate length to backscatter radar waves efficiently can be dispersed around the nose cone in a huge cloud to produce so much clutter in the radar receiver that the nose cone signal is effectively lost. To be sure of destroying the warhead, the defense

would be forced to attack each balloon decoy or the entire cloud of wires, expending a prohibitively large number of interceptors.

Despite this difficulty, a mid-course defense could be useful against limited missile attacks or primitive attacks that do not employ sophisticated decoys. Such attacks should be considered in evaluating the worth of a defense since nuclear technology is bound to spread to less developed countries. For this purpose mid-course defense might provide a substantial degree of protection for the whole country for only a few billion dollars. Mid-course defense can also be useful as an adjunct to an expensive terminal system--designed to cope with larger, more sophisticated attacks--like that discussed in the next section.

Nike Zeus

The problem for mid-course defense is decoys. But effective decoys are heavier and harder to make if they have to penetrate the atmosphere. This fact has led the United States to spend most of its effort on defenses that intercept during the terminal phase of the trajectory.

To perform the standard functions of a defense, i.e. to detect and track incoming objects, to discriminate warheads from lightweight decoys, and then to launch and direct interceptors to the target, a terminal ballistic missile defense system has the following major components: an acquisition radar, target-track radars, a computer for data handling, nuclear-armed interceptors and radars to track them. The acquisition radar detects and identifies the incoming objects, hands over this information to the tracking radar, which follows the objects on their courses and causes the intercepting missiles to be committed. The main point for the reader to appreciate about these components is that they are big, complex and expensive.

To see why, remember that the terminal phase lasts less than a minute. Much of this time may be spent in discriminating decoys from the warhead before an interceptor is actually launched. To insure that an intercept takes place at a high altitude--where ground effects

from the enemy explosion, as well as the defense explosion, are negligible--the interceptor must be fast. To carry a warhead, guidance and control equipment, and rocket motors to maneuver at high altitude, the interceptor must be big. The interceptor used in the Nike Zeus system--the first U.S. system of this kind--weighs more than twenty thousand pounds, is almost fifty feet long and travels at an average speed of a little more than one mile per second.

The acquisition radar must also be big. The typical nose cone is much smaller than an airplane and, because of its more regular shape, can be so designed that it does not reflect much of the radar wave back to the receiver. To see such a target at the necessary range--a few hundred miles--requires a powerful radar with a big antenna. Because of the submarine-launched missile threat and the round-the-world missile, as well as the ICBM's, the narrow-pencil radar beam must be scanned over a large fraction of the sky, and the scanning must be rapid because the time the missiles are in view is so short. In the Nike Zeus acquisition radar, the scanning is done by mechanical means, which involves precision machinery on a large scale.

Another major complication is caused by the requirement to carry out many intercepts simultaneously. To accomplish this task Nike Zeus provides a separate target-track radar for each object, which is very expensive since the target-track radar, while smaller than the acquisition radar, is still by usual standards a large and complex device.

Finally, the short time scale of the ballistic missile defense problem forces the defense to rely on automatic target handling. To cope with many simultaneous objects and to perform calculations necessary for discrimination and tracking, a large digital computer is an essential component of a terminal defense system.

Nike-X

Nike Zeus was a successful program; all the components worked. Prototype tests have been carried out in Kwajalein in the Pacific against targets launched from Vandenberg Air Force Base in California.

But, in the last analysis, many experts felt that the decoy problem had not really been solved.

The Zeus interceptor, to achieve an acceptable intercept altitude, has to be committed very early in the terminal phase, at a time when there has been only a small amount of atmospheric interaction with the incoming objects, which--it was feared--was not adequate for discrimination of lightweight decoys. Also it became clear, from U.S. high-altitude nuclear tests, that in the altitude regime in which the Nike Zeus system has to operate, the acquisition radar can be blacked out by high-altitude nuclear explosions deliberately set off by the enemy outside the reach of the defense.

To cope with both these problems, it was proposed that the Nike philosophy of permitting only negligible damage to the ground be altered so that the commitment and intercept altitudes could be lowered. Out of this concept has come a new system--currently under development--called Nike-X.

The essential component of the Nike-X system is a new interceptor--the Sprint--which can attain its maximum speed in a very short time. It is this interceptor that allows the defense to wait as long as possible for discrimination and still achieve an acceptable intercept altitude. Also included in the system are some Zeus interceptors in order to preserve the capability of intercepting at high altitude when feasible. The combined system--with capability to intercept at both high and low altitudes--is much more difficult to overcome than either singly. In addition, the Nike-X system has a new acquisition radar, which employs electronic rather than mechanical scanning of the beam and allows many more objects to be tracked simultaneously without fear of saturating the defense.

If the development program goes as expected, the Nike-X system should be effective in intercepting enemy warheads that are aimed directly at the defended cities. Unfortunately, for a terminal defense like Nike-X, the warheads can be made to impact on the ground outside the reach of the defense, allowing the winds to carry radioactive fallout over the cities. Such fallout is without effect on houses and

other structures but its radiation is dangerous to man. For this reason the Nike-X system cannot stand by itself. Fallout shelters to protect people from the radiation are a necessary adjunct.

Actually, it is helpful to the Nike system if the population has some protection from blast and heat as well as fallout. That way the intercept altitude can be made very low without excessive damage to the population if the enemy warhead is detonated before the intercept occurs. The lower the intercept altitude, the more certain it is that decoys can be distinguished from the warhead.

So far we have been concerned with the technical feasibility of terminal defense. But we must ask: if the system is feasible, what is its value? Frequently, it is assumed that feasibility implies great value, but the answer is not so simple. The defense interceptors are very expensive. To insure that none of the warheads "leaks" through the defense--because of unreliability of the system components--several defense interceptors may have to be fired at each threatening object. The cost of these interceptors plus the cost of radars, computers, etc. is measured in millions of dollars per object shot down. Such a defense may be valueless if for the same cost the offense is able to overwhelm the defense with warheads and decoys.

Which side has the advantage in this game depends sensitively on the minimum weight for an effective decoy and on a myriad of other details. For the Nike-X system, the answer is not known, and the estimates are secret. In his statement before the House Armed Services Committee in February 1965, Secretary of Defense McNamara stated that analyses indicate that the advantage probably lies with the offense by a factor of about two or more. However, he also pointed out that the United States has great economic superiority over other nations and hence may be able to afford this kind of disadvantage. Moreover, while we must consider the possibility that the Soviets would try to offset our defense by increasing their offensive forces, we naturally hope that they would not react that way at all. It might better serve the ends of both countries if the Soviets were to choose instead to strengthen their own defenses.

Comparison of Active and Passive Defense

We must now turn to the question we asked at the beginning of this chapter: which is more effective, active or passive defense--or some combination of the two? In the last section we pointed out that the Nike X ballistic missile defense may be overcome by additional offensive forces with the cost-advantage (probably) on the side of the offense. The obvious question at this point is: can the effect of blast shelters be offset in the same way?

A simple argument gives the answer. Assume that warning time is too short for evacuation, and people must be sheltered close to where they live or work. The cost for shelters is so much per person depending upon the hardness level, i.e. how much blast pressure can be tolerated. Hence, the cost to defend a given area to a given hardness is proportional to the population density. On the other hand, the cost to the offense to destroy the area depends only on the area and is independent of the population density. It follows that the exchange ratio--the defense cost relative to the offense cost to offset the defense--is favorable to the defense in all those places where the population density is sufficiently low.

The critical population density depends upon several factors: the offense cost to deliver a nuclear warhead, the defense cost of a shelter space, and the shelter hardness. The reason that the hardness plays a role is that the cost of a shelter space happens to be almost independent of hardness, at least up to a blast pressure of about 100 pounds per square inch (psi), while the offense cost per person killed increases rapidly with increased hardness. If 100 psi shelters cost three hundred dollars per space and the offense cost to deliver a ten megaton warhead is thirty-five million dollars, the critical population density is about fifteen thousand per square mile. A range of ten to twenty-five thousand probably covers the uncertainties in the cost figures.

More than ninety percent of the people in the United States live in places where the population density is less than fifteen thousand per square mile. All these people could be protected by 100 psi blast shelters that cost less than the missiles required to destroy the

shelters. It follows that for this major portion of the population, if a choice were made between purely active terminal or purely passive defense, passive defense would be preferred.

We are left with the question: what kind of defense should be provided for the remaining population--less than ten percent--that live in the densely populated areas? For these areas, with the assumptions we have made about cost and effectiveness of pure passive or pure active defense, neither approach is satisfactory. Both can be offset for less cost by the offense.

Of course there is the possibility that some new ballistic missile defense, as yet uninvented, could be less expensive than the Nike system, or that people could be evacuated from the densely populated regions, for instance by a system of tunnels as described elsewhere in this book. Another possibility is that a combination of active and passive defense might be more effective than either by itself.

That such a cooperative interaction between the two types of defense should exist, can be seen this way: if there are only blast shelters, no active defense, the offense need not use decoys or multiple warheads and can devote his entire missile payload to the most efficiently packaged nuclear weapons. Against ballistic missile defense only, the offense can afford to employ a large fraction of his payload for penetration aids such as decoys or multiple warheads since even a small warhead on target is adequate against an unsheltered populace. When both types of defense are present, however, the offense is forced to compromise.

A simplified analysis of this complex offense-defense game shows that a cooperative effect does exist and specifically, if M_a is the price in missiles that the defense can exact for each life destroyed using active defense only, M_p is the price using passive defense only, then, by proper allocation of resources between the two, the price can be raised to something like the sum, $M_a + M_p$. For the low-population regions, as might be expected from our previous argument, M_p turns out to be much larger than M_a , which means that passive defense dominates and the cooperative effect is negligible. For the high-population density regions, however, M_a may become comparable to M_p --

depending on detailed cost assumptions--and the cooperative effect can be as much as a factor of two. A factor of two seems significant when one remembers that tens of billions of dollars are involved and that much of this money would be spent in these high-population density regions in order to make them no more attractive as targets than the rest of the country (in terms of population destroyed per missile). In fact, a factor of two would go a long way toward overcoming the disadvantage of the defense in the high-population density areas. For these areas, therefore, it is to be expected that an optimum defense would consist of a combination of active and passive types.

Of course the analysis permits a precise determination of the optimum distribution of active and passive defense. We can actually calculate, for a fixed total defense budget, how much should be spent on each type in each part of the country. Unfortunately, the results of such an analysis cannot be taken too literally, since they are terribly sensitive to technical inputs, many of which are unknown. The best one can do with these technical inputs is to make plausible assumptions of the sort underlying Secretary McNamara's statements (in 1965) to Congress on Nike-X, and then quote the results in no more detail than they deserve. In this spirit, for defense budgets up to say 50 billion dollars, the situation can be represented fairly well by three categories.

First, there are the rural areas and small towns, where, because of the low-population densities, direct attack is unprofitable. This category--comprising roughly half the population--would receive fallout protection but no special protection from blast and no terminal ballistic missile defense.

The second category is the suburban areas. To make this category no more attractive as a target than the first category, blast protection as well as protection against fallout must be provided, but still no terminal ballistic missile defense. The level of blast protection might range from 10 to 100 psi depending upon the total defense budget, the population density, and the increase in cost with increasing hardness of the shelters. If the cost increase is as low as indicated in the next chapter, the hardness may well be 100 psi almost everywhere. This second category comprises roughly forty percent of the population.

The third category is the large central cities, which are prime targets for attack. For this category all types of defense are provided--fallout, blast and ballistic missile defense. The fraction of the budget devoted to active defense increases with the population density and reaches a maximum in the New York metropolitan area of 25 to 50 percent, depending on cost assumptions.

We have already emphasized that quantitative results of this type of analysis cannot be trusted because of technical uncertainties. Actually, the most important of these uncertainties have to do with active defense. Vital parameters such as decoy weight and warhead characteristics may differ appreciably from what is assumed, since our knowledge of present enemy technology is limited and there is always the possibility of future invention. Furthermore, the performance of active defense under wartime conditions is unpredictable because realistic testing is impossible.

On the other hand, blast shelters that work--at least up to 100 psi or so--involve only straightforward engineering well within the present state-of-the-art. For these reasons passive defense, at least for population, seems to be a more assured damage limiting measure than ballistic missile defense, and hence the preferable form of defense. Moreover, in the analysis it has been tacitly assumed that a shelter hardness greater than 100 psi is not practical. If this assumption proves false and much harder shelters can be built for a modest cost increase, the analysis would tend to favor passive defense even more heavily. If, for example, 500 psi is achievable at a cost of five hundred dollars per person, then even for a large defense budget--fifty billion dollars--the allocation for active defense would be negligible everywhere, even in New York City. These considerations suggest that all defense money should be spent on passive measures. However, there are some factors that work in the opposite direction.

We have been assuming that the only purpose of defense is to maximize the number of lives saved against a well-planned attack on U.S. cities--the sort of attack the Soviets might be capable of launching against us if they were to strike first. We have also assumed that there is adequate warning of the attack, from long-range radars

or other intelligence sources, so that people have time to get into the shelters.

The picture is somewhat modified and favors greater emphasis on ballistic missile defense if the protection of houses, structures, and other material assets is taken into consideration as well. It is difficult to be quantitative because a detailed evaluation would involve a comparison between the values of such disparate entities as human lives and factories.

The picture is further modified if the missile attack comes with little or no warning. With passive defense only, people would not have a chance to get into the shelters, and such an attack would be devastating. But active defense, being continuously alert, can counter the early-arriving missiles and provide additional time for occupying the shelters.

Finally, consideration should be given to attacks that are limited in the number and sophistication of arriving warheads, for instance attacks by lesser powers. In this case, ballistic missile defense--even an area defense--might be able to destroy all the incoming warheads and provide complete protection for lives and property. With passive defense only, there would necessarily be some lives lost and appreciable damage to property.

For all these reasons, it seems clear that a portion of the defense budget should be allocated to ballistic missile defense. There is, of course, no exact way to determine what this portion should be, and some judgment must enter into the final decision. For a budget of 50 billion dollars, a way of allocating that seems to us to have merit is to spend most of the defense money, 35 billion dollars, for fallout and blast shelters; about half the remainder for a mid-course--area--ballistic missile defense, designed to provide some protection for the whole country, including our strategic missiles, strategic bombers and bomber defenses; and the other half for a terminal ballistic missile defense to protect the most populous urban areas.